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# Aviva Stadium: A case study in integrated parametric design

Roly Hudson, Paul Shepherd and David Hines



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## Abstract

The nature of large complex buildings requires specialized skills across a multi-disciplinary team and high levels of collaboration and communication. By taking a parametric approach to design and construction, high quality results can be delivered on budget on time. This type of approach facilitates the opportunity for design teams to work in an iterative manner. A parametric model reduces the time associated with complex design changes while providing a centralized method for coordinating communication. In this paper the recently completed Aviva Stadium is used to illustrate the ways in which these benefits manifest themselves on built work. The authors identify the moments in the design and construction process that truly justify the effort in implementing a parametric approach. By approaching design in this way a “design conversation” can take place between parties involved, resulting in a better building.

## I. INTRODUCTION

This is the second of two papers focused on the Aviva Stadium in Dublin. In this paper the design and construction process that is fully documented in the preceding paper is examined and reflected on. The implications of applying a customised parametric approach are identified, discussed and illustrated with scenarios that took place during the development of the stadium.

The Aviva Stadium, Dublin, is the first building to be designed from start to finish using commercially available parametric modelling software. A single model in Bentley's GenerativeComponents (GC) was shared between architects and engineers, which allowed the optimized design of form, structure and façade. This shared model facilitated dynamic design conversations between the architects, engineers, the client, local planners, contractors and cladding sub-contractors. Conversations involve the exchange of ideas between multiple parties, who often have different points of view or experience. The participants in these conversations learn from them as they are exposed to the knowledge of others. The ability to communicate ideas, incorporate knowledge and learn from the other specialists involved in the Aviva Stadium resulted in a unique project. Through reflections on the process of design and production of this building, a series of design dialogues can be identified that took place at different times and involved different parties. The common thread between them was the use of a parametric model, which allowed discourse to take place and resulted in design decisions being made and the project moving forward. By identifying the specific instances where these discussions occurred during the Aviva Stadium design process, the authors demonstrate the benefit of parametric approaches in general. This paper draws on previous published material which describes in detail the parametric modeling strategy [1 & 2] and reflects on the implications for architectural design in practice and theory [1 & 3]. Now the building is complete, the whole process can be examined and the interdisciplinary communication possibilities that the process enabled can be described.

A parametric geometry definition was at the core of the workflow. This was shared by the architects and engineers, and defined the root of a hierarchical control system. The use of fragmented and hierarchical structures in design problems has been identified by Rowe [4] and Simon [5]. The recursive nature of this in parametric modelling in contemporary practice has been observed by Hudson [1]. Examples of this approach and in particular its application to parametric control methods can be seen in the early work of the Specialist Modelling Group at Foster and Partners [6 & 7]. The geometric definition of the Aviva Stadium was further fragmented into a set of control devices which provided the architectural team with the means to work through a series of design proposals, and to present them internally to the design team and externally to the client and local planners.

The same model was extended by the structural engineering team to incorporate detailed information on all structural support members for the roof. This allowed full bi-directional exchange of information between engineer and architect so that the effects of changes to the building envelope on the structure could be quickly assessed, and similarly the impact in terms of sightlines and aesthetics of the placement of structural members could be assessed. The parametric approach also allowed the engineers to pass detailed three dimensional models directly to their team of analysts who could make detailed calculations on structural performance and engage in a discussion on how to optimise the roof support system.

In parallel a further branch to the base geometric definition was being developed; the cladding model. This was focused on developing manufacturing details and exploring geometric methods for defining the façade system. This required close collaboration between the architects, contractors and specialist cladding contractors, which was primarily enabled by the parametric model. As the detail of the assembly of the façade was under development, a method for controlling the position of the façade panels was established and tested, which required the architects to work closely with mechanical engineers to fulfil the ventilation requirements of the building whilst ensuring the aesthetic concepts were not compromised. In the detail development phase of the project the parametric definition again provided the means of communication and coordinating requirements and checking proposed shop drawings of design details within the architectural geometry definition.

## 2. GEOMETRIC CONTROL

The underlying process structure or workflow separated the envelope definition and control from the definitions and control of structural and cladding geometry as illustrated [1 and 3]. This approach allows independent specialists to work on different levels of the design at different levels of detail simultaneously as ultimately they are all tied into the same building model, which communicated changes across the design team. The approach is dependent on early collaboration in order to clearly define thresholds between areas of responsibility.

For the Aviva Stadium this approach to parametric design allowed many alternative design studies (conversations) to be undertaken by various parties. This can be seen very clearly where the model was shared between architects and engineers and is discussed in section 3. To communicate with the client body and local planners the architectural team could undertake geometry studies with simple initial cladding definitions and convey these ideas as two dimensional drawings and renderings. Meanwhile the details of the cladding system were still being developed. The value of this ability to approach a design task where different levels of detail are tackled simultaneously can be seen when there is a downstream requirement to

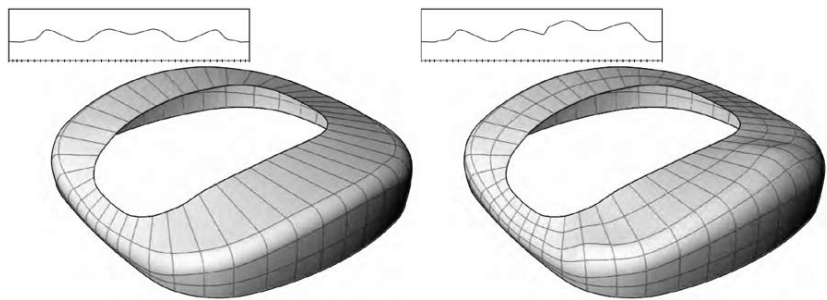
make significant design change. The need to adjust the footprint of the Aviva Stadium is an example of this. This was necessary to accommodate the depth of the cladding system and to ensure that the building volume was maximized but did not exceed the site boundaries. The depth of the cladding assembly was unknown when the footprint was initially defined so it was essential to implement this design change once relevant information was available.

Further benefits of this approach can also be identified in communication that took place within the architectural practice. The envelope definition was further fragmented into a lower level of static geometry, interactive graphical control curves and numeric values in a spreadsheet. Ideas from the broader architectural design team could be communicated and incorporated into the design in various ways that engaged the broad range of skills found in an architectural practice. The structural grid was referenced into the model as a static CAD file which any Microstation user could edit and the changes would be incorporated into the geometric definition.

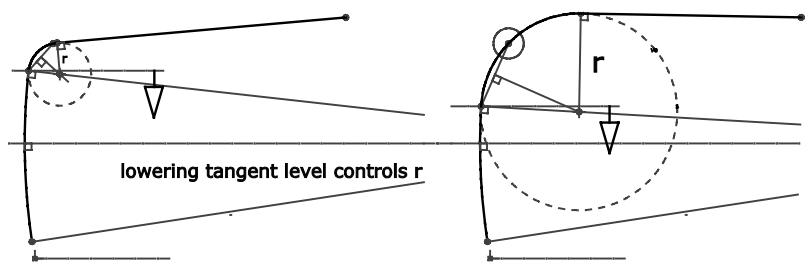
The interactive control curves or “law curves” are two-dimensional geometric objects controlled by the user to describe how a set of values change. For example a single control curve could describe how the heights of a row of columns vary and this system could describe heights for an infinite number of columns with just a few user positioned control points. On the Aviva Stadium this control device was found to act both as a tool for communicating design intent and also as a method of checking the current state of the model. Design intent in terms of the form of the envelope was determined by manipulating the control curves to sculpt the shape (Figure 1). Inspection of the control curves also provided a visual check of surface smoothness.

This form of visual optimization provided the architects with the ability to fine-tune geometry based on input from across the architectural team. The hierarchical structure of the control system provided the option of adding further control as the project progressed. One example of this is the additional aesthetic control that was required for the area where the wall cladding transitions into roof cladding. This was defined in the model by an arc in section on each grid-line, which filleted between the top of the wall and the straight roof section (Figure 2). This arc was initially defined as having a single radius throughout the stadium. The use of initial arbitrary “place-holder” parameter values in parametric modeling is a key technique and is described in detail in relation to architectural problem solving [1]. Assigning architectural place holder geometry is equivalent to assigning initial parameter values, a generalized description of this is given by Motta and Zdrahal [8]. The benefit of placeholder geometry was seen on the Aviva Stadium when it was later realised that a higher level of control was necessary for this radius as it contributed significantly to the overall form of the stadium. An additional

control curve was added that provided a means of locally controlling fillet radius on each grid-line around the stadium (Figure 1).

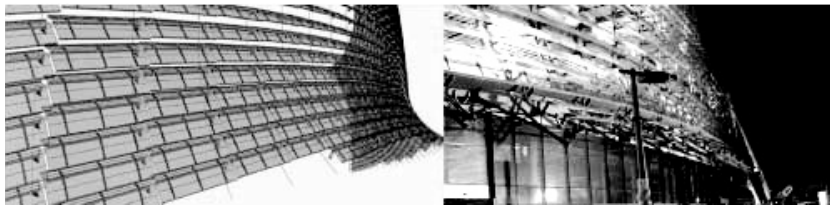


◀ Figure 1: Adjusting the fillet radius.



◀ Figure 2: Aesthetic control parameter.

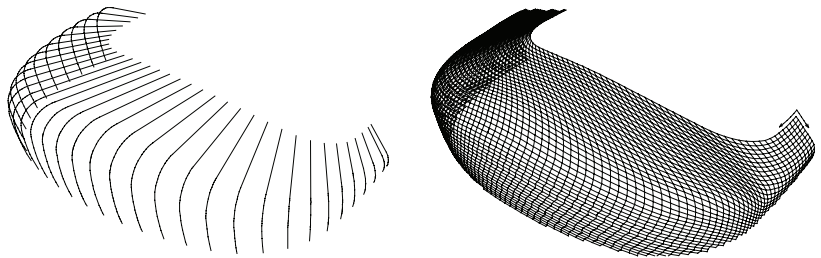
The control structure was further adapted to include a localized lifting of the façade that formed a canopy over the entrance area. In this case the form of the canopy was developed as a non-parametric component but the nature of the parametric model allowed this static definition to be combined as part of the overall control strategy. This illustrates the way in which the parametric model allowed a more integrated approach to take place within the architectural design team that provided a means of communication. This shows how a centralized geometric definition can be established by recombining the distributed control of specific parts of the building; structural grid, variation in section form and canopy geometry.



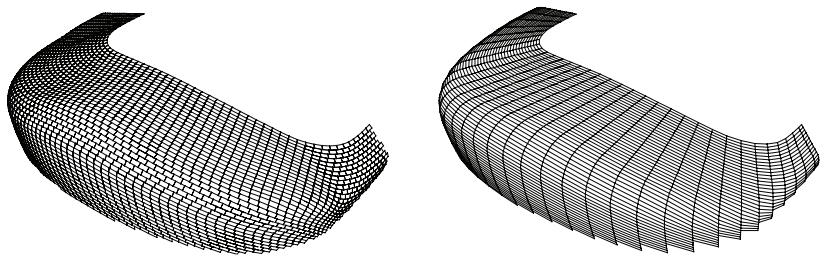
◀ Figure 3: Canopy 3D model and as built.

Once established, the envelope control system provided the means to facilitate a dialogue between the architects, local planners and client body. A simplified cladding strategy was defined that consisted of panels following the underlying geometry and simply represented as a series of four sided polygons. Combined with the control mechanism this approach allowed several different versions of setting out methods to be investigated. These included various patterns involving flat and twisted panels (Figures 4, 5 & 6). Several quickly produced parametric models provided the design team the graphical means to communicate internally and to describe their intentions to the client and decisions were made regarding the function and appearance of the system. Functionally the established control mechanism allowed the rain runoff direction and to be studied on each panel (Figure 6 left) and to ensure the fall angle along each section was always 5 degrees or greater.

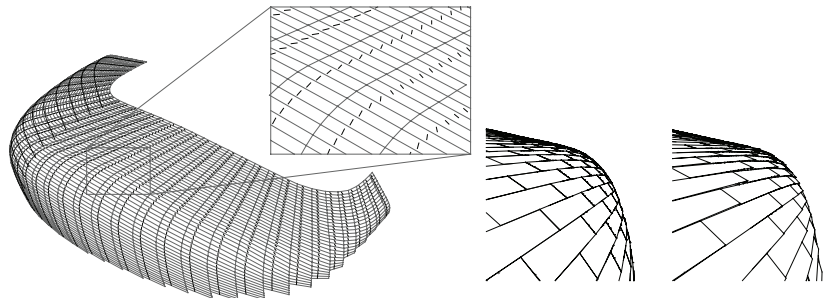
► Figure 4: Left: Underlying geometry. Right: Rectangular array of panels over surface.



► Figure 5: Left: Brick bond setting out. Right: Array of panels with varied numbers in each bay.



► Figure 6: Left: Water run-off directions. Right: Visual comparison of warped and planar panels





### 3. STRUCTURE

The parametric modelling of Aviva Stadium clearly demonstrates how a single model definition can be used as a communication tool to share information between architect and engineer. The structural engineering team were issued with a parametric definition of the envelope geometry as a GC script file, along with a set of corresponding numeric input parameters stored in a spreadsheet. The structural definition was undertaken with the same software and used the envelope definition as its base. Changes to the geometry by the architects were recorded in the spreadsheet, which could be reissued. The structural model would then upload these new parameters and define new roof steelwork geometry based on the updated envelope.

Implementing this process on Aviva Stadium indicated several considerations which need to be addressed when applying a shared parametric definition in practice. The first is the importance of making early agreements in terms of naming conventions of geometry within the model and agreeing the order in which the geometry will be generated. Early meetings were held between both parties to agree naming conventions and parameterisation methods for the envelope model. Care was taken to avoid changes to naming of geometry and order of construction to the architectural parametric model during the design. Carelessness in this process would have caused problems with the engineer's model, which referenced, and was dependent on, specifically named objects in the architectural model.

It was important to clearly identify the ultimate responsibility for defining parameters in this process of sharing a parametric definition. The shared system used for Aviva Stadium restricted all changes to the envelope geometry to the architect and changes to the structural member layout could only be performed by the engineering team. However, if these restrictions could have been relaxed, it would have allowed the engineers the opportunity to make direct adjustments to the geometry of the envelope, and may have allowed further improvements to the efficiency of the structure to have been made.

The main conversation regarding the structural design of the Aviva Stadium was carried out in order to optimise the structural performance of the roof. Very large steel trusses were conceived to support the weight of the roof and to withstand the extra forces induced on the structure during the life of the building from snow, wind, etc. The roof steelwork is clearly a major part of the overall stadium design and had huge implications in terms of aesthetic, sightlines and cost. There was the potential for significant efficiencies to be made by optimising both the layout of the steelwork and the sizes of the individual members. Specialist software was written by the engineering design team to automatically create a 3D structural analysis model directly from the parametric model. This model not only converted

the geometry of the roof steelwork, but also defined member sizes, support conditions and more importantly applied dead-, live- and wind-loads directly into the structural analysis model such that it was able to be analysed without any manual intervention. The calculation of loads was of particular importance, since the amount of load each member supports is actually dependent on the geometry of the envelope itself. Therefore this connection between engineer and analyst facilitated an in-depth discussion and investigation of the structural roof scheme, where options could be tested very quickly and an efficient solution developed. At the same time, any changes to the envelope geometry instigated by the architects could be seamlessly incorporated into this discussion, without the need to stop and re-create analysis models.

## 4. CLADDING DESIGN DEVELOPMENT

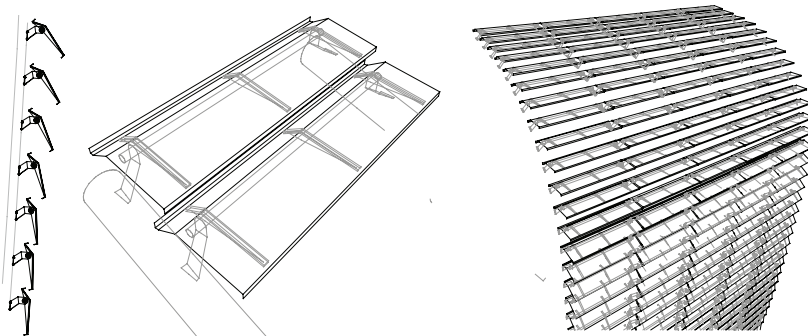
The cladding design task involved developing a bespoke facade system and followed an iterative process. At each stage parametric models were produced that combined specialist knowledge and provided the means for communicating this knowledge between the architectural design team, the client body, facade design specialists and the cladding contractor (responsible for the manufacture of the parts). The models produced at each stage captured the current knowledge of the cladding system and this formed a basis for decision making and the final design for the built system gradually emerged. The cladding design development phase illustrates the way in which a parametric representation of a partially complete design can be constructed using place holder objects and control mechanisms. Working in this way enables the development of knowledge of the design problem. As new understanding is formalised and is substituted for the place holders in the model that knowledge is then captured and higher level design decision making can take place. This method of working on design problems is identified by Chandrasekaran [9] as a sequence of “propose-critique-modify” where design development takes place cyclically.

The first stage of cladding development was described in section 2 and involved adjusting envelope geometry to satisfy functional and aesthetic intent of the architects with approval from the planners and client body. The next step involved investigating two options for panel assembly systems which were driven by the involvement of expert manufacturing knowledge (Figure 7). Using the parametric framework to explicitly model the geometry of each assembly type, three-dimensional models could be created, allowing aesthetic evaluation and quantitative information extraction to calculate cost, both to deliver and maintain each system. Based on this evaluation an assembly was selected. This decision imposed geometric constraints on the model as the panels needed to be planar and use a standard profile and bracket to fix back onto the supporting structure of the facade.

The next phase was focused on developing these requirements. The result of this was the development of standardised brackets for supporting panel assemblies and the algorithmic knowledge for automating the positioning of these across the entire facade. The proposed brackets had two axes of rotation and an algorithm was required to calculate these angles based on the position of surrounding panels. Using this algorithm it was possible to produce three-dimensional models to test that the proposed system worked over the whole stadium. Based on this, the dimensions of the brackets were refined. The model defined three-dimensional geometry which was used to produce rendered images for aesthetic evaluation in client presentations and at planning approval meetings.

The penultimate iteration of the facade design process involved developing the parametric facade model to provide a way to balance three conflicting criteria; facade ventilation, ingress of windblown rain and an aesthetic concept. Figure 10 illustrates the cyclic process that was captured in this stage. This is described in more detail in the following section where the process of configuring the facade is identified as a specific example of a parametric model providing the means of visually optimising for a series of interdependent functional requirements.

The final iteration of the cladding design process involved developing the method for construction documentation. Through close collaboration with the facade sub-contractors a data format was developed for the issuing of information was developed. In this way the specialist knowledge of the facade sub-contractors became captured in the model. The facade was broken into seven sections defined by the proposed construction sequence. Each section was sub-divided into structural bays. For each bay, two geometric models were produced and for each panel five numerical parameters written to cells in a spreadsheet. The process was tested with a full scale three storey mock up (Figure 8).



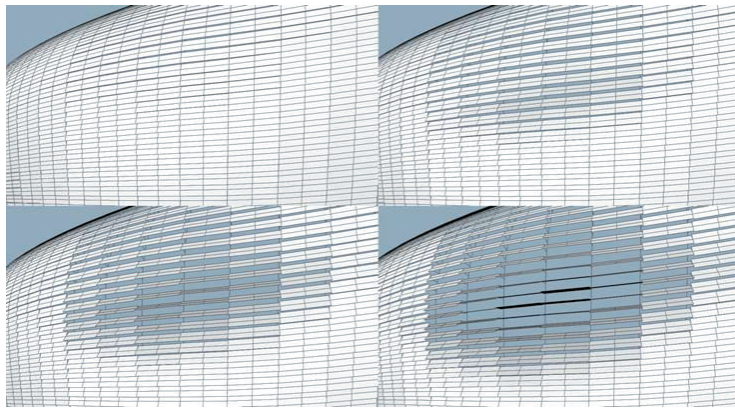
◀ Figure 7: Left to right: Facade section. Polycarbonate panel assembly. Panels on facade

► Figure 8: Mock up

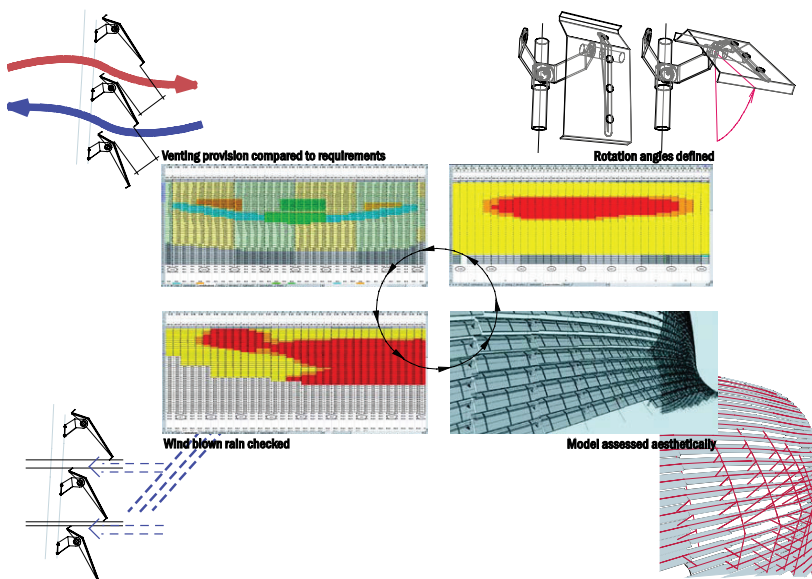


## 5. FAÇADE CONFIGURATION

This section describes the way in which the parametric model provided the means of communication for developing a functional and visual optimisation system. Using a parametric model to provide the means to undertake visual optimisation has been identified by Glymph et al [10] and used to rationalise a glass roof. For the Aviva Stadium the process involved the combination of input from mechanical engineers and the aesthetic control from the architectural design team. The parametric model was configured to enable geometric and aesthetic implications to be studied in relation to quantitative performance data which was used to inform design changes. The proposed cladding panels had a lateral axis of rotation and this allowed the system to operate like a shingle roof. The axis also meant some panels could be fixed in an open position to provide air intake and exhaust for air handling units located behind the facade. The aesthetic concept was defined using a series of quickly produced simple models that demonstrated how areas of open panels could be "blended" into the surrounding facade by smoothly reducing the open angle in panels around the open area (Figure 9). These simple models captured a description of the design intent over a small area but a system to control the whole the facade was required.

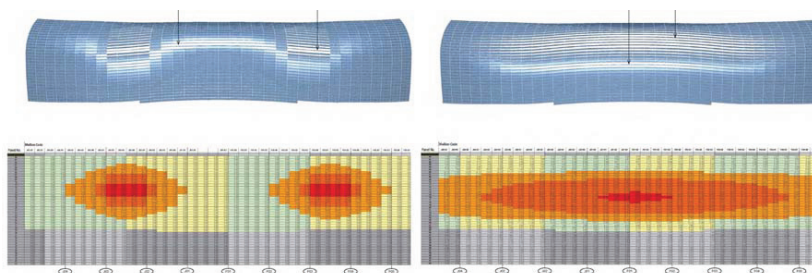


◀ Figure 9: Cladding design concept.



◀ Figure 10: Cyclic model for panel system development

This was implemented by mapping individual panel rotation angles contained in cells within a spreadsheet, representing the facade, to the parametric model (Figure 11 bottom). Within the spreadsheet the location and extent of open areas was specified and fall off in angle was defined by functions.



◀ Figure 11: Elevations (top) of facades generated by rotation angles in spreadsheet (below)



The design task for this iteration was to specify rotation values to meet the demands of the aesthetic concept driven by the architectural design team while providing requirements for intake and exhaust areas supplied by mechanical engineers. In addition it was necessary to limit the chances of windblown rain through vertical gaps between panels where blended areas extended beyond the air handling units. A design loop was implemented in the parametric model whereby rotation values were proposed, ventilation areas and windblown gap dimensions written to a spreadsheet and a three-dimensional model produced (Figure 10). Using these numeric and geometric representations a configuration could be proposed and then critiqued.

The focus was the provision of ventilation to air handling units. The ventilation area provided by each panel was mapped to the spreadsheet-elevation. Examining this showed areas provided by each panel and the total for an entire set of panels. Similarly the effect of wind-blown rain could be seen panel by panel. Because these spreadsheet-elevations were representations of the facade it was possible to deduce the corresponding rotation values that would need to be modified in order to improve the ventilation values while minimising the effect of wind-blown rain. Figure 12 illustrates the final result of this process showing a detail of a completed portion of the facade.

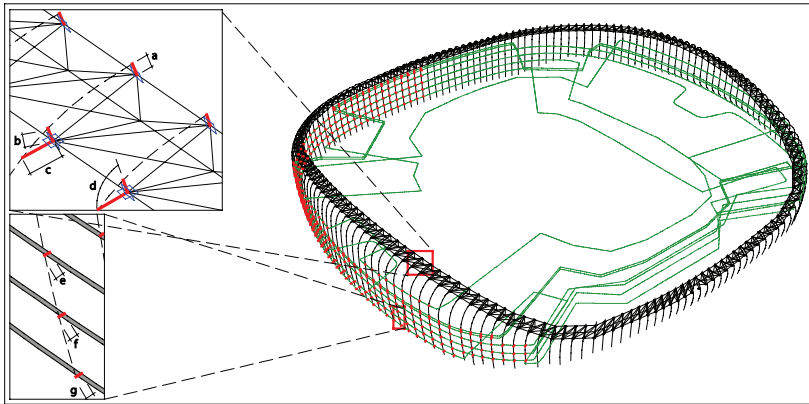
► Figure 12: Built facade



## 6. DETAIL DESIGN

The detail design phase illustrates how the parametric model allowed communication between the cladding sub-contractors (William Cox and CLAD Engineering (responsible for detail design and manufacture)) and the

architects (Populous). The model was extended to generate ranges of dimensions at fixing locations that defined the tolerances required by each detail. The geometry of proposed details could be loaded into the model and clashes detected. The model was also used to check that there were no clashes between panels. The rationalisation of acoustic panels in the edge truss was investigated.



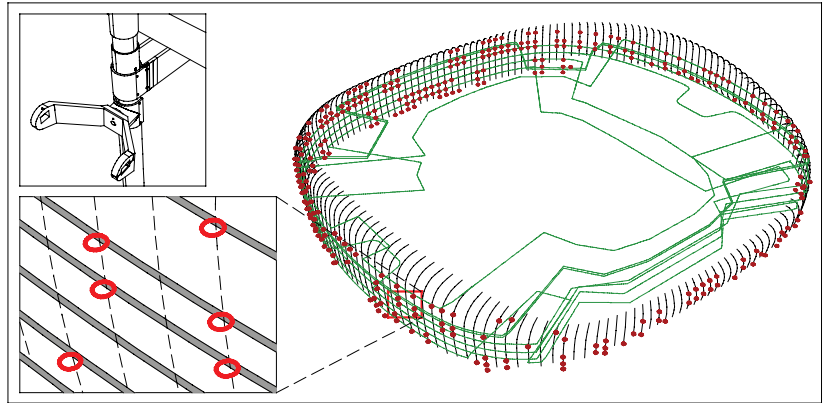
◀ Figure 13: Measuring tolerances.

The detail design phase was driven by the cladding sub-contractor's work and progress was monitored at a series of design meetings held at the architects London office. These were attended by the main contractor (SISK), project manager, structural engineers (Buro Happold), the architects and when necessary other sub-contractors whose work interfaced with the cladding sub-contractors. At these meetings, the cladding sub-contractors would report on the progress of the detail design, all involved would be able to comment. The cladding sub-contractor's response to the undulating geometry of the stadium was a series of generic details that could accommodate a range of geometrically different fixing points. In order to support the detail cladding design phase, following a request by the main contractors several, quickly constructed parametric models were produced. These were used to determine ranges of angular and dimensional differences that the generic connections needed to accommodate (Figure 13). Other models were developed to check for clashes between the facade panel brackets and the connection between mullion and floor slab (Figure 14). Parametric modelling was also used in the development process for a series of other detail design elements. These included a rationalised acoustic panelling system (Figure 15), a strip of gutter panels at the base of the facade and checking for clashes between all neighbouring panels (Figure 16).

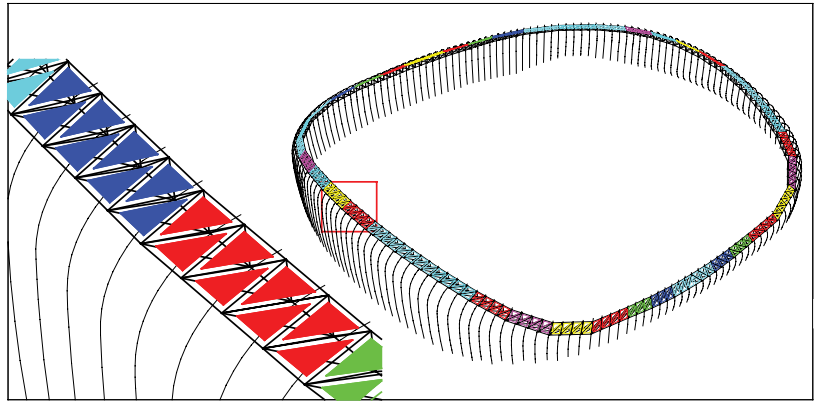
A series of checking procedures were also incorporated into the model by the architectural team to ensure coordination across all packages. This involved developing existing models to incorporate details proposed by more than one contractor such as between steel design and the facade

system. These checks enabled the architects to avoid extensive manual work and approve the detail design proposals for construction.

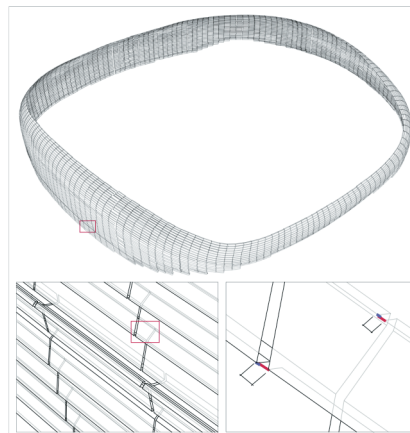
► Figure 14: Clash locations.



► Figure 15: Acoustic panel rationalisation.



► Figure 16: Gap check between panels.





## 7. CONCLUSION

The series of instances illustrated herein demonstrate how the parametric approach taken in the design and construction of The Aviva Stadium enabled a series of design conversations to take place. These dialogues were able to take place at various levels of detail simultaneously. Breadth of design possibilities were tackled with the local planners and client at the same time as methods for assembling and controlling the façade systems were being developed. Similarly, work simultaneously took place amongst different groups within the project. Within the architectural practice the parametric approach provided a variety of ways for a range of skill levels to interact with the model and communicate design intent. A working relationship was built with the contractor and specialist cladding design team that was dependant on the parametric model acting as a conduit for information leaving the architectural practice and returning in the form of shop drawings. This improved the design through advanced levels of collaboration facilitated by parametric definition and sharing. The project indicates an approach to developing and delivering designs where a bespoke building information model is defined. In this mode of operation, the design team decides on the information included in the model and what and how it is extracted based on the specific needs of manufacturers and collaborators. This approach to building design development is dependent on software that encourages extension through scriptable, user defined and reconfigurable tool sets.

## Acknowledgements

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